PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference	**FOR FURTHER ACTION**	see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.
P/61761/PC		
International application No.	International filing date *(day/month/year)*	(Earliest) Priority Date *(day/month/year)*
PCT/GB 00/ 00994	17/03/2000	19/03/1999
Applicant		
MARCONI CASWELL LIMITED		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language,** the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

   [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

   [ ] contained in the international application in written form.

   [ ] filed together with the international application in computer readable form.

   [ ] furnished subsequently to this Authority in written form.

   [ ] furnished subsequently to this Authority in computer readble form.

   [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

   [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).

3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title,**

   [X] the text is approved as submitted by the applicant.

   [ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract,**

   [X] the text is approved as submitted by the applicant.

   [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawing** to be published with the abstract is Figure No. 1

   [X] as suggested by the applicant.

   [ ] because the applicant failed to suggest a figure.

   [ ] because this figure better characterizes the invention.

   [ ] None of the figures.

INTERNATIONAL SEARCH REPORT

International Application No
P[redacted]B 00/00994

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01L1/24 G01D5/353

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01L G01D G01H G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 680 489 A (KERSEY ALAN D) 21 October 1997 (1997-10-21) abstract; figures 1,4 column 1, line 5 -column 3, line 19	1-19
A	PUTNAM M A ET AL: "BROADBAND SQUARE-PULSE OPERATION OF A PASIVELY MODE-LOCKED FIBER LASTER FOR FIBER BRAGG GRATING INTERROGATION" OPTICS LETTERS,US,OPTICAL SOCIETY OF AMERICA, WASHINGTON, vol. 23, no. 2, 15 January 1998 (1998-01-15), pages 138-140, XP000733981 ISSN: 0146-9592 the whole document	1-19

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 June 2000	16/06/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Helm, B

2

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
P[redacted]B 00/00994

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 216 565 A (PLESSEY OVERSEAS) 1 April 1987 (1987-04-01) abstract; figures 1-3 column 3, line 25 -column 4, line 64	1-19

2

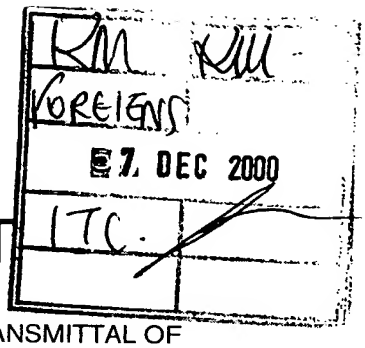
INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PC[redacted]B 00/00994

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5680489 A	21-10-1997	AU 2808797 A	21-01-1998
		CA 2259184 A	08-01-1998
		EP 0958517 A	24-11-1999
		WO 9800740 A	08-01-1998
EP 0216565 A	01-04-1987	AT 63006 T	15-05-1991
		AU 582893 B	13-04-1989
		AU 6247686 A	12-03-1987
		CA 1272625 A	14-08-1990
		DE 3678886 D	29-05-1991
		JP 62111212 A	22-05-1987
		NZ 217520 A	30-05-1988
		US 4795226 A	03-01-1989

PATENT COOPERATION TREATY



From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To:

Hoste, Colin, Francis
MARCONI INTELLECTUAL PROPERTY
Waterhouse Lane
Chelmsford, Essex CM1 2QX
GRANDE BRETAGNE

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL PRELIMINARY EXAMINATION REPORT
(PCT Rule 71.1)

Date of mailing *(day/month/year)*	05.12.2000
Applicant's or agent's file reference P/61761/PC	**IMPORTANT NOTIFICATION**

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/GB00/00994	17/03/2000	19/03/1999

Applicant
MARCONI CASWELL LIMITED

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.

2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.

3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.

4. **REMINDER**

The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices) (Article 39(1)) (see also the reminder sent by the International Bureau with Form PCT/IB/301).

Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide.

Name and mailing address of the IPEA/	Authorized officer
European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Schießl, W-P Tel.+49 89 2399-2860

Form PCT/IPEA/416 (July 1992)

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
P/61761/PC		
International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/GB00/00994	17/03/2000	19/03/1999
International Patent Classification (IPC) or national classification and IPC G01L1/24		
Applicant MARCONI CASWELL LIMITED		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 6 sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☒ Certain defects in the international application
   - VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
13/10/2000	05.12.2000
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Helm, B Telephone No. +49 89 2399 2366

Form PCT/IPEA/409 (cover sheet) (January 1994)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB00/00994

I. Basis of the report

1. This report has been drawn on the basis of *(substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments (Rules 70.16 and 70.17).)*:
Description, pages:

1-14 as originally filed

Claims, No.:

1-19 as originally filed

Drawings, sheets:

1/3-3/3 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-19
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-19
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-19
	No:	Claims	

2. Citations and explanations
   see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

Re Item V.: Reasoned statement under Article 35(2)

1. Prior Art

The following documents have been considered for the purposes of this report:

D1 = US-A-5 680 489

D2 = OPTICS LETTERS, PUTNAM M.A. ET AL: "BROADBAND SQUARE-PULSE OPERATION OF A PASSIVELY MODE-LOCKED FIBER LASER FOR FIBER BRAGG GRATING INTERROGATION", VOL. 23, NO. 2, JANUARY 15, 1998, US, WASHINGTON, PAGES 138-140

D3 = EP-A-0 216 565

2. Technical Field

The invention relates to an apparatus for and a method of sensing strain with an optical fibre Bragg grating (FBG) sensor having a plurality of reflecting Bragg gratings arranged along the length of an optical fiber. Each grating has a unique location along the fiber and a unique wavelength component for reflecting incident light. Each unique wavelength component of the gratings is altered when subjected to strain. Consequently, each grating may be interrogated by conventional wavelength-division multiplexing (WDM) and time-division multiplexing (TDM) techniques.

3. Closest and Most Relevant Prior Art

Document D1 or D2, each of them disclosing FBG strain sensor arrays which are interrogated by a combination of WDM and TDM.

4. Novelty (Article 33(2) PCT)

The present invention as it is defined in the independent claims 1 and 13 differs from the known apparatus and method essentially by the following features:
An arrangement for interrogating a FBG sensor array using a combined **intensity**

and wavelength division multiplexing (IWDM) is provided: The reflectivities of adjacent reflecting structures (gratings) are configured to be different such that the intensity of light reflected from adjacent structures can be used to discriminate between them.
Therefore, claims 1 and 13 are new.

5. Inventive Step (Article 33(3) PCT)

IWDM allows the number of sensing gratings in an array to be doubled without sacrificing dynamic range and without additional cost or complexity of interrogation. Therefore, an inventive step is acknowledged.

6. Documents Cited in the International Search Report

No document discloses or suggests an IWDM technique.
Documents D1 and D2 each describe a combined WDM and TDM approach.
Document D3 also discloses a FBG strain sensor array. This document mentions that the reflectivities of the respective diffraction gratings could be varied. However, the sensor according to D3 is arranged as a heterodyne interferometer, wherein all the gratings are arranged to reflect light at the **same** characteristic wavelength so that no WDM is possible. Accordingly, document D3 relates to a technical field which is completely different from that of D1 and D2.

7. Dependent Claims

Dependent claims 2 to 12 and 14 to 19 relate to additional features of the independent claims to which they refer and are therefore deemed to be novel and inventive.

8. Industrial Applicability (Article 33(4) PCT)

Beyond any doubt, the invention, as it is defined in claims 1 to 19, is industrially applicable.

Re Item VII.: Certain defects in the international application

1. Contrary to the requirements of Rule 5.1(a)(ii) PCT, the relevant background art disclosed in the documents D1 and D2 is not mentioned in the description, nor are these documents identified therein.

2. The paragraph on page 9, lines 10 to 11 of the present description is not drafted in accordance with the PCT Preliminary Examination Guidelines PCT/GL/3, Chapter II, 4.17.

3. The sentence bridging pages 13 and 14 of the present description is not drafted in accordance with the PCT Preliminary Examination Guidelines PCT/GL/3, Chapter III, 4.3a.

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF THE RECORDING OF A CHANGE

(PCT Rule 92bis.1 and Administrative Instructions, Section 422)

To:

TOLFREE, Roger, Keith
Marconi Intellectual Property
Waterhouse Lane
Chelmsford
Essex CM1 2QX
ROYAUME-UNI

Date of mailing (day/month/year)
26 February 2001 (26.02.01)

Applicant's or agent's file reference
P/61761.WOP/

IMPORTANT NOTIFICATION

International application No.
PCT/GB00/00994

International filing date (day/month/year)
17 March 2000 (17.03.00)

1. The following indications appeared on record concerning:

[ ] the applicant [ ] the inventor [X] the agent [ ] the common representative

Name and Address
HOSTE, Colin, Francis
Marconi Intellectual Property
Waterhouse Lane
Chelmsford
Essex CM1 2QX
United Kingdom

State of Nationality:
State of Residence:
Telephone No.: +44 (0) 1245 275454
Facsimile No.: +44 (0) 1245 275114
Teleprinter No.:

2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

[X] the person [ ] the name [ ] the address [ ] the nationality [ ] the residence

Name and Address
TOLFREE, Roger, Keith
Marconi Intellectual Property
Waterhouse Lane
Chelmsford
Essex CM1 2QX
United Kingdom

State of Nationality:
State of Residence:
Telephone No.: +44 (0) 1245 275563
Facsimile No.: +44 (0) 1245 275469
Teleprinter No.:

3. Further observations, if necessary:

4. A copy of this notification has been sent to:

[X] the receiving Office
[ ] the International Searching Authority
[X] the International Preliminary Examining Authority
[ ] the designated Offices concerned
[X] the elected Offices concerned
[ ] other:

The International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland

Facsimile No.: (41-22) 740.14.35

Authorized officer
R. Chrem

Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF THE RECORDING OF A CHANGE

(PCT Rule 92bis.1 and Administrative Instructions, Section 422)

To:

HOSTE, Colin, Francis
Marconi Intellectual Property
Waterhouse Lane
Chelmsford
Essex CM1 2QX
ROYAUME-UNI

Date of mailing (day/month/year) 24 January 2001 (24.01.01)	
Applicant's or agent's file reference P/61761/PC	**IMPORTANT NOTIFICATION**
International application No. PCT/GB00/00994	**International filing date** (day/month/year) 17 March 2000 (17.03.00)

1. The following indications appeared on record concerning:

[X] the applicant [ ] the inventor [ ] the agent [ ] the common representative

Name and Address	State of Nationality	State of Residence
MARCONI CASWELL LIMITED One Bruton Street London WIX 8AQ United Kingdom	GB	GB
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

[ ] the person [ ] the name [X] the address [ ] the nationality [ ] the residence

Name and Address	State of Nationality	State of Residence
MARCONI CASWELL LIMITED One Bruton Street London WIJ 6AQ United Kingdom	GB	GB
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

3. Further observations, if necessary:

4. A copy of this notification has been sent to:

[X] the receiving Office
[ ] the International Searching Authority
[X] the International Preliminary Examining Authority
[ ] the designated Offices concerned
[X] the elected Offices concerned
[ ] other:

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland**	Authorized officer R. Chrem
Facsimile No.: (41-22) 740.14.35	Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Commissioner
US Department of Commerce
United States Patent and Trademark
Office, PCT
2011 South Clark Place Room
CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 20 November 2000 (20.11.00)	
International application No. PCT/GB00/00994	**Applicant's or agent's file reference** P/61761/PC
International filing date (day/month/year) 17 March 2000 (17.03.00)	**Priority date** (day/month/year) 19 March 1999 (19.03.99)
Applicant GROVES-KIRKBY, Christopher et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International Preliminary Examining Authority on:

13 October 2000 (13.10.00)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was

[ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland

Facsimile No.: (41-22) 740.14.35

Authorized officer

Pascal Piriou

Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF RECEIPT OF RECORD COPY

(PCT Rule 24.2(a))

To:

HOSTE, Colin, Francis
Marconi Intellectual Property
Waterhouse Lane
Chelmsford
Essex CM1 2QX
ROYAUME-UNI

15 MAY 2000

Date of mailing (day/month/year)	IMPORTANT NOTIFICATION
03 May 2000 (03.05.00)	
Applicant's or agent's file reference	**International application No.**
P/61761/PC	PCT/GB00/00994

The applicant is hereby notified that the International Bureau has received the record copy of the international application as detailed below.

Name(s) of the applicant(s) and State(s) for which they are applicants:

MARCONI CASWELL LIMITED (for all designated States except US)
GROVES-KIRKBY, Christopher et al (for US)

International filing date	:	17 March 2000 (17.03.00)
Priority date(s) claimed	:	19 March 1999 (19.03.99)
Date of receipt of the record copy by the International Bureau	:	04 April 2000 (04.04.00)
List of designated Offices	:	

EP :AT,BE,CH,CY,DE,DK,ES,FI,FR,GB,GR,IE,IT,LU,MC,NL,PT,SE
National :AU,CA,JP,US

ATTENTION

The applicant should carefully check the data appearing in this Notification. In case of any discrepancy between these data and the indications in the international application, the applicant should immediately inform the International Bureau.

In addition, the applicant's attention is drawn to the information contained in the Annex, relating to:

- [X] time limits for entry into the national phase
- [X] confirmation of precautionary designations
- [X] requirements regarding priority documents

A copy of this Notification is being sent to the receiving Office and to the International Searching Authority.

The International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland

Facsimile No. (41-22) 740.14.35

Authorized officer:

R. Chrem

Telephone No. (41-22) 338.83.38

International application No.
[redacted] PCT/GB00/00994

INFORMATION ON TIME LIMITS FOR ENTERING THE NATIONAL PHASE

The applicant is reminded that the "national phase" must be entered before each of the designated Offices indicated in the Notification of Receipt of Record Copy (Form PCT/IB/301) by paying national fees and furnishing translations, as prescribed by the applicable national laws.

The time limit for performing these procedural acts is **20 MONTHS** from the priority date or, for those designated States which the applicant elects in a demand for international preliminary examination or in a later election, **30 MONTHS** from the priority date, provided that the election is made before the expiration of 19 months from the priority date. Some designated (or elected) Offices have fixed time limits which expire even later than 20 or 30 months from the priority date. In other Offices an extension of time or grace period, in some cases upon payment of an additional fee, is available.

In addition to these procedural acts, the applicant may also have to comply with other special requirements applicable in certain Offices. **It is the applicant's responsibility** to ensure that the necessary steps to enter the national phase are taken in a timely fashion. Most designated Offices do not issue reminders to applicants in connection with the entry into the national phase.

For detailed information about the procedural acts to be performed to enter the national phase before each designated Office, the applicable time limits and possible extensions of time or grace periods, and any other requirements, see the relevant Chapters of Volume II of the PCT Applicant's Guide. Information about the requirements for filing a demand for international preliminary examination is set out in Chapter IX of Volume I of the PCT Applicant's Guide.

GR and ES became bound by PCT Chapter II on 7 September 1996 and 6 September 1997, respectively, and may, therefore, be elected in a demand or a later election filed on or after 7 September 1996 and 6 September 1997, respectively, regardless of the filing date of the international application. (See second paragraph above.)

Note that only an applicant who is a national or resident of a PCT Contracting State which is bound by Chapter II has the right to file a demand for international preliminary examination.

CONFIRMATION OF PRECAUTIONARY DESIGNATIONS

This notification lists only specific designations made under Rule 4.9(a) in the request. It is important to check that these designations are correct. Errors in designations can be corrected where precautionary designations have been made under Rule 4.9(b). The applicant is hereby reminded that any precautionary designations may be confirmed according to Rule 4.9(c) before the expiration of 15 months from the priority date. If it is not confirmed, it will automatically be regarded as withdrawn by the applicant. There will be no reminder and no invitation. Confirmation of a designation consists of the filing of a notice specifying the designated State concerned (with an indication of the kind of protection or treatment desired) and the payment of the designation and confirmation fees. Confirmation must reach the receiving Office within the 15-month time limit.

REQUIREMENTS REGARDING PRIORITY DOCUMENTS

For applicants who have not yet complied with the requirements regarding priority documents, the following is recalled.

Where the priority of an earlier national, regional or international application is claimed, the applicant must submit a copy of the said earlier application, certified by the authority with which it was filed ("the priority document") to the receiving Office (which will transmit it to the International Bureau) or directly to the International Bureau, before the expiration of 16 months from the priority date, provided that any such priority document may still be submitted to the International Bureau before that date of international publication of the international application, in which case that document will be considered to have been received by the International Bureau on the last day of the 16-month time limit (Rule 17.1(a)).

Where the priority document is issued by the receiving Office, the applicant may, instead of submitting the priority document, request the receiving Office to prepare and transmit the priority document to the International Bureau. Such request must be made before the expiration of the 16-month time limit and may be subjected by the receiving Office to the payment of a fee (Rule 17.1(b)).

If the priority document concerned is not submitted to the International Bureau or if the request to the receiving Office to prepare and transmit the priority document has not been made (and the corresponding fee, if any, paid) within the applicable time limit indicated under the preceding paragraphs, any designated State may disregard the priority claim, provided that no designated Office may disregard the priority claim concerned before giving the applicant an opportunity to furnish the priority document within a time limit which is reasonable under the circumstances.

Where several priorities are claimed, the priority date to be considered for the purposes of computing the 16-month time limit is the filing date of the earliest application whose priority is claimed.

PATENT COOPERATION TREATY

PCT

NOTIFICATION OF THE RECORDING OF A CHANGE

(PCT Rule 92bis.1 and Administrative Instructions, Section 422)

From the INTERNATIONAL BUREAU

To:

HOSTE, Colin, Francis
Marconi Intellectual Property
Waterhouse Lane
Chelmsford
Essex CM1 2QX
ROYAUME-UNI

Date of mailing (day/month/year) 24 January 2001 (24.01.01)	
Applicant's or agent's file reference P/61761/PC	**IMPORTANT NOTIFICATION**
International application No. PCT/GB00/00994	**International filing date** (day/month/year) 17 March 2000 (17.03.00)

1. The following indications appeared on record concerning:

[X] the applicant [ ] the inventor [ ] the agent [ ] the common representative

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	Teleprinter No.	

2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

[ ] the person [ ] the name [X] the address [ ] the nationality [ ] the residence

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3. Further observations, if necessary:

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[ ] the International Searching Authority
[X] the International Preliminary Examining Authority
[ ] the designated Offices concerned
[X] the elected Offices concerned
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Facsimile No.: (41-22) 740.14.35	Telephone No.: (41-22) 338.83.38

Form PCT/IB/306 (March 1994)

003793448

WO 00/57148
PCT/GB00/00994

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTICE INFORMING THE APPLICANT OF THE COMMUNICATION OF THE INTERNATIONAL APPLICATION TO THE DESIGNATED OFFICES

(PCT Rule 47.1(c), first sentence)

To:
HOSTE, Colin, Francis
Marconi Intellectual Property
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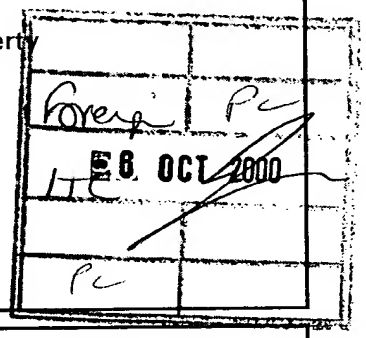

Date of mailing (day/month/year) 28 September 2000 (28.09.00)	
Applicant's or agent's file reference P/61761/PC	**IMPORTANT NOTICE**

International application No.	**International filing date** (day/month/year)	**Priority date** (day/month/year)
PCT/GB00/00994	17 March 2000 (17.03.00)	19 March 1999 (19.03.99)

Applicant
MARCONI CASWELL LIMITED et al

1. Notice is hereby given that the International Bureau has communicated, as provided in Article 20, the international application to the following designated Offices on the date indicated above as the date of mailing of this Notice:
   AU,US

   In accordance with Rule 47.1(c), third sentence, those Offices will accept the present Notice as conclusive evidence that the communication of the international application has duly taken place on the date of mailing indicated above and no copy of the international application is required to be furnished by the applicant to the designated Office(s).

2. The following designated Offices have waived the requirement for such a communication at this time:
   CA,EP,JP

   The communication will be made to those Offices only upon their request. Furthermore, those Offices do not require the applicant to furnish a copy of the international application (Rule 49.1(a-bis)).

3. Enclosed with this Notice is a copy of the international application as published by the International Bureau on
   28 September 2000 (28.09.00) under No. WO 00/57148

REMINDER REGARDING CHAPTER II (Article 31(2)(a) and Rule 54.2)

If the applicant wishes to postpone entry into the national phase until 30 months (or later in some Offices) from the priority date, **a demand for international preliminary examination** must be filed with the competent International Preliminary Examining Authority before the expiration of 19 months from the priority date.

It is the applicant's sole responsibility to monitor the 19-month time limit.

Note that only an applicant who is a national or resident of a PCT Contracting State which is bound by Chapter II has the right to file a demand for international preliminary examination.

REMINDER REGARDING ENTRY INTO THE NATIONAL PHASE (Article 22 or 39(1))

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(PCT Rule 61.3)

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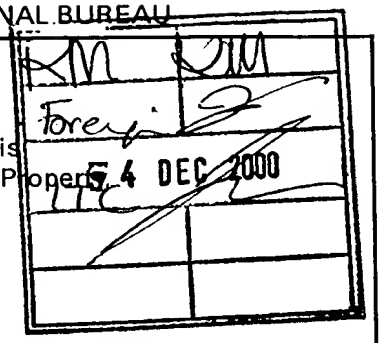

Date of mailing (day/month/year) 20 November 2000 (20.11.00)		
Applicant's or agent's file reference P/61761/PC	**IMPORTANT INFORMATION**	
International application No. PCT/GB00/00994	**International filing date** (day/month/year) 17 March 2000 (17.03.00)	**Priority date** (day/month/year) 19 March 1999 (19.03.99)
Applicant MARCONI CASWELL LIMITED et al		

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Pascal Piriou

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PATENT COOPERATION TREATY

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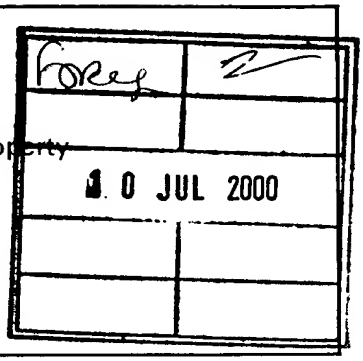

Date of mailing (day/month/year) 26 June 2000 (26.06.00)	
Applicant's or agent's file reference P/61761/PC	**IMPORTANT NOTIFICATION**
International application No. PCT/GB00/00994	International filing date (day/month/year) 17 March 2000 (17.03.00)
International publication date (day/month/year) Not yet published	Priority date (day/month/year) 19 March 1999 (19.03.99)
Applicant MARCONI CASWELL LIMITED et al	

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2. This updates and replaces any previously issued notification concerning submission or transmittal of priority documents.

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Priority date	Priority application No.	Country or regional Office or PCT receiving Office	Date of receipt of priority document
19 Marc 1999 (19.03.99)	9906361.2	GB	19 June 2000 (19.06.00)

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International Bureau

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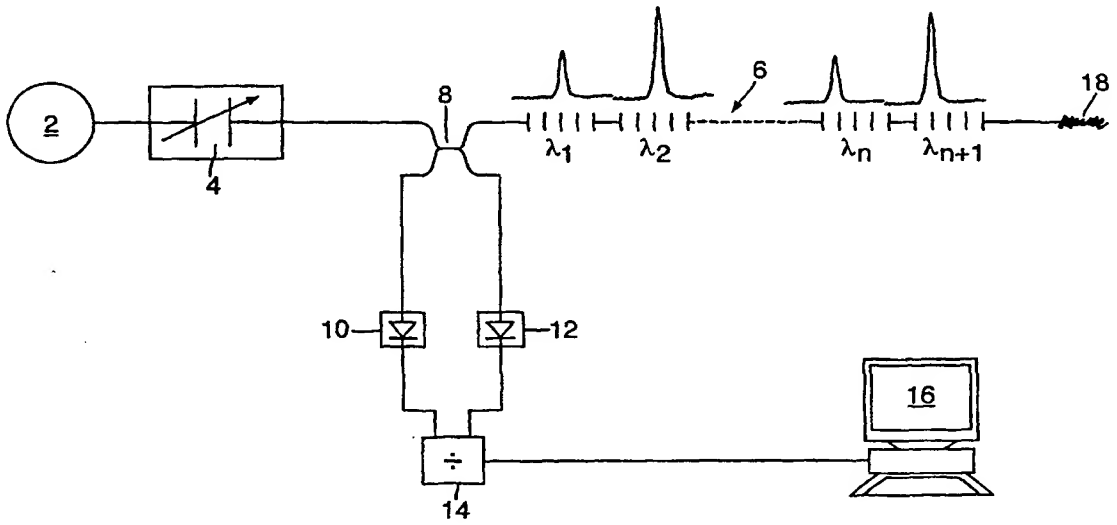

(57) Abstract

A strain sensor comprises an optical waveguide (6) having a plurality of reflecting structures (Bragg gratings) along its length. Each structure reflects light at a different characteristic wavelength (λ_1 to λ_{n+1}) which changes in dependence on a change of physical length of at least part of the reflecting structure. The reflectivity of reflecting structures which reflect at characteristic wavelengths which are adjacent to each other (λ_1 and λ_2 or λ_n and λ_{n+1}) are configured to be different such that the intensity of light reflected from adjacent structures can be used to discriminate between them.

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STRAIN SENSING

This invention relates to strain sensing and more especially to a strain sensor, apparatus for use with and a method of operating a strain sensor for sensing structural health and load monitoring.

Structural health and load monitoring of structures such as bridges and buildings is well known. Typically such systems measure the tensile or compressive strain within the structure, that is the change of length (extension or contraction) relative to the original length, which is indicative of the loading of the structure. Such information can be used in assessing damage and warning of impending weakness in the structural integrity of structures such as aircraft, space platforms, marine vessels, bridges and other structures as well as in their engineering design.

To measure strain within such structures it is known to use a strain sensor. Early strain sensors relied on a change in electrical resistance with strain and typically comprised four terminal devices in which two terminals were used to apply electrical current to the device and the other two for accurately sensing the potential difference developed across it. A particular disadvantage of such electrical resistance sensors is that when it is required to measure strain at a large number of points, as would be the case in structural monitoring of structures such as bridges and buildings, such sensors require a very large number of electrical connections, making them cumbersome and prone to electrical failure.

More recently optical fibre strain sensors have been proposed which overcome a number of the problems of electrical resistance sensors. Optical fibre strain sensors comprise an optical fibre containing a number of components which are responsive to applied strain. Such components can comprise birefringent elements, micro-bends, Fabry-Perot resonators or intra-core Bragg gratings. In the case of the latter which are often termed fibre Bragg gratings, each Bragg grating which itself constitutes a respective strain sensor, reflects light at a characteristic wavelength which is determined by the pitch of the grating. This characteristic wavelength will change if the optical fibre is subjected to tensile or compressional strain which affects the pitch of the grating. Strain is measured by measuring a change in the characteristic wavelength of each grating. By providing a number of gratings along the length of the fibre, each of which reflects light at a different characteristic wavelength, it is possible to measure strain at a number of different points along the optical fibre.

Optical fibre strain sensors offer a number of advantages compared to electrical strain sensing techniques, making them attractive for structural health monitoring applications. For example, the Bragg grating characteristic wavelength is a linear function of change in grating pitch; fibre Bragg gratings are inherently wavelength encoded and consequently problems of intensity magnitude variation are eliminated, being fully integrated within the optical fibre eliminates any point of mechanical weakness, they are immune to electro-magnetic interference (EMI), are lightweight, resistant to corrosion and fatigue, inherently safe in that they cannot initiate fires or explosions and are compatible with fibre reinforced materials. In relation to the latter their compatibility has lead to the emergence of so-called "smart structures" which structurally integrate optical fibre

sensors thereby enabling continual monitoring of the internal strain of the structure and/or any load to which it is subjected.

Whilst optical fibre strain sensing is found to be effective the inventors have appreciated that it suffers from certain limitations. Fibre Bragg gratings can be addressed in the wavelength, time and space domains. The number of fibre Bragg grating sensors that can be integrated into a single fibre and addressed by wavelength multiplexing is limited which is a consequence of the limited spectral range of the optical sources which are used to operate such sensor systems. Typically, the spectral range of the currently available optical sources is 30 to 40 nm and it is usually required to be able to measure strains in the region of 3,000 to 5000 $\mu\varepsilon$ (that is a 0.3% - 0.5% mechanical extension/contraction) which corresponds to a change in the characteristic wavelength of between 3 to 5 nm. In order to effectively operate a number of Bragg grating sensors within a single optical fibre it is necessary to dedicate a well defined wavelength range to each sensor to ensure that at its maximum wavelength change the characteristic wavelength of any given sensor cannot intrude upon the wavelength range of the sensor in the adjacent wavelength band since, under these conditions, it is impossible to discriminate between light reflected from the two sensors. As a result the number of gratings that can be incorporated in a single fibre is limited.

The present invention has arisen in an endeavour to overcome at least in part the limitations of the known strain sensing arrangements.

According to the present invention a strain sensor comprises an optical waveguide having

a plurality of reflecting structures along its length, wherein each structure reflects light at a different characteristic wavelength which changes in dependence on a change of physical length of at least part of the reflecting structure; characterised in that the reflectivity of reflecting structures which reflect at characteristic wavelengths which are adjacent to each other are configured to be different such that the intensity of light reflected from adjacent structures can be used to discriminate between them. Since discrimination between the reflection characteristics of structures which are adjacent in wavelength is based on the relative magnitude of their reflectivities, this allows reflecting structures to have overlapping wavelength bands thereby enabling more reflecting structures to be incorporated within an optical waveguide for a given optical spectral range.

By securing the regions of the optical waveguide which include the reflecting structures, to an object, any change in length of the object will cause a change in the length of the reflecting structure which will be detected as a change in the characteristic wavelength. Furthermore, if these regions of the optical waveguide are placed in thermal contact with an object, any change in temperature will cause a change in the physical length of the reflecting structure which will be detected as a change in characteristic wavelength and the strain sensor of the present invention thus acts as an effective temperature sensor. It will be appreciated that in both measuring strain and temperature the strain sensor measures a change in the length of at least a part of the reflecting structure, that is it measures an internal strain of the sensor. In the context of the present invention the term strain sensor is intended to be construed broadly as a sensor which relies on a change in length and should not be restricted to a sensor which is for measuring strain in an object

to which it is attached.

Advantageously the reflecting structures which reflect at adjacent wavelengths are configured such that one structure reflects light at one characteristic wavelength and the structure adjacent in wavelength is selected to reflect light at two characteristic wavelengths. Preferably the reflecting structure which reflects light at two characteristic wavelengths is configured such that the two wavelengths are separated by at least the width of the reflection characteristic of the structure which reflects at the adjacent wavelength. Such an arrangement is particularly advantageous since at least one of the pair of characteristic wavelengths always remains resolvable and therefore discrimination between the reflecting structures is possible.

Most conveniently the optical waveguide comprises an optical fibre and preferably the or each reflecting structure comprises a grating structure, most preferably a Bragg grating, in which a change in the characteristic wavelength is in consequence of a change in the pitch of the grating. In a preferred implementation the optical fibre includes a photo refractive dopant, such as for example a silica optical fibre doped with germanium oxide, and the or each grating structure is optically written into the fibre core by, for example, exposing the fibre to ultra-violet (UV) holographic projection. In such a case the spacing of the fringes of the holographic projection determines the pitch and hence the characteristic wavelength of the grating and the intensity of the UV light determines the reflectivity at the characteristic wavelength.

According to a second aspect of the invention an apparatus for measuring strain

comprises a strain sensor described above; a light source operable to apply light to the waveguide of the sensor, said light having a wavelength range which covers at least the range of wavelengths over which the reflecting structures reflect and detector means for determining the change of characteristic wavelength at which each reflecting structure reflects light, said changes being indicative of a change in length of at least a part of the respective reflecting structure.

Preferably the detector means determines the changes in characteristic wavelength by measuring the wavelengths at which the sensor reflects light. Since the strain sensor only reflects light at various characteristic wavelengths, any light which is not reflected will pass along the optical waveguide substantially unattenuated. As a result, at the far end of the waveguide the changes in wavelength will appear as a change in attenuation of transmitted light. In an alternative arrangement the detector means measures light transmitted by the sensor and determines the changes by measuring the changes in wavelength at which light transmission is attenuated.

In a particularly preferred form of apparatus the detector means further comprises means for utilising the relative magnitude of the intensity of the reflected light or the relative magnitude of the intensity at which light transmission is attenuated to discriminate between reflecting structures which are adjacent in wavelength.

According to yet a further aspect of the invention a method of measuring strain comprises providing a strain sensor described above; applying light to the waveguide of the sensor, said light having a wavelength range which covers at least the range of wavelengths over

which the reflecting structure reflects light, and detecting any change in the characteristic wavelength at which the reflecting structures reflect light. Preferably the changes in characteristic wavelength are detected by measuring the wavelengths at which the sensor reflects light.

Alternatively the changes in characteristic wavelength can be detected by measuring the wavelengths at which the transmission of light through the sensor is attenuated.

Preferably the method further comprises detecting the relative magnitude of the intensity of reflected light or the relative magnitude of the intensity at which transmitted light is attenuated to discriminate between reflecting structures which are adjacent in wavelength.

When it is desired to measure strain within an object the method further comprises securing a part of the waveguide having at least a part of one of the reflecting structures to the object such that a change in the physical length of the object causes a change in the physical length of the reflecting structure. Alternatively, or in addition, when it is desired to measure the temperature of an object, the method further comprises placing a part of the waveguide having at least a part of one of the reflecting structures in thermal contact with the object such that a change in the temperature of the object causes a change in the physical length of at least a part of the reflecting structure.

In order that the invention may be better understood a strain sensor and apparatus in accordance with the invention for measuring strain and/or temperature will now be described by way of example only with reference to the accompanying drawings in

which:

Figure 1 is a schematic of a strain and/or temperature sensing apparatus in accordance with the invention;

Figure 2(a) is a series of plots of measured reflectivity I versus wavelength for different applied strains for the apparatus of Figure 1;

Figure 2(b) is a plot of the measured wavelength shift $\Delta\lambda$ of the peak (x) of Figure 2(a) versus strain;

Figure 3(a) is a series of plots of measured reflectivity I versus wavelength for a further strain sensor for different applied strains; and

Figure 3(b) is a plot of the measured wavelength shift $\Delta\lambda$ for the two peaks (x,y) of Figure 3(a) versus strain.

Referring to Figure 1 a strain sensing apparatus comprises a broad band light source 2, a tunable filter 4, an optical fibre strain sensor 6, a directional coupler 8, two photodiodes 10 and 12 respectively, a mixer circuit 14 and a processor 16. The optical fibre strain sensor 6, which is a key aspect of the present invention and considered inventive in its own right, comprises a silica optical fibre which is doped germanium oxide. Spaced along the length of the optical fibre there are provided within the core of the optical fibre a plurality of Bragg diffraction gratings. Each grating is produced within the core of the

optical fibre by exposing the core of the fibre to ultra-violet (UV) light using holographic exposure, though other techniques such as a phase mask or point by point writing can be used. Germanium oxide is a photo refractive dopant which when exposed to UV light results in a permanent change of refractive index and hence a Bragg diffraction grating can be defined within the core by exposing the core to an appropriate pattern of UV light. Each grating structure within the fibre is selected to have a characteristic wavelength, denoted λ_1 to λ_{n+1} in Figure 1, which is determined by the pitch of the respective grating. The method of producing optical fibre gratings using holographic projection is known and is for example described in an article by one of the inventors in the GEC Journal of Technology Volume 15 Number 1, 1998, paragraph 2.3, which is hereby incorporated by way of reference thereto.

The gratings which reflect at adjacent wavelengths, for example λ_1 and λ_2 or λ_n and λ_{n+1} in Figure 1 are arranged to alternately have reflectivities of 50 and 95% respectively which will hereinafter be referred to as "low" and "high" reflectivity. Using the fabrication technique described this difference in reflectivity is achieved by altering the intensity of the UV light used to expose and so define the grating structure within the fibre. As will become apparent the absolute reflectivity of gratings which are adjacent in wavelength is not critical and the use of 50 and 95% are exemplary only. The important criterion is that the relative reflectivity of gratings which are adjacent in wavelength have sufficiently different reflectivities to enable discrimination between light reflected from the respective gratings. The optical fibre sensor 6 further comprises associated with each grating region mechanical securing means to enable the fibre to be mechanically secured to an object whose strain is to be measured. Such mechanical

securing means can comprise an encapsulating tube, flanges or mounting brackets made of metal, glass or a plastics material, to which the fibre is connected either by adhesive or by mechanical clamping.

The broad band light source 2, which conveniently comprises a light emitting diode or Erbium doped fibre amplifier, is operable to produce a continuous broad band light output over the wavelength range 1550 nm $\pm$ 30 nm. This continuous light output is applied to the wavelength selective filter 4, which can comprise for example an acousto-optic tuneable filter or a scanned Fabry-Perot filter, such that the filter produces an optical output which is swept over the range of wavelengths of the broad band source 2. In an alternative arrangement the light source 2 and tuneable filter 4 can be replaced with a suitable optical source which is tuneable in the wavelength domain such as for example a tuneable laser diode. The swept light output is applied to the first input of the directional coupler 8 which splits the light such that half passes into and along the optical fibre sensor 6 and the other half passes to the first photodiode 10. Light which is reflected by the Bragg gratings in the optical fibre sensor 6 travels back toward the directional coupler 8 where it is split such that half passes to the second photodiode 12 and the remaining half towards the wavelength selective filter 4. The light which is not reflected by the optical fibre sensor 6 passes along the length of the optical fibre and is dissipated in a light dump 18 at the far end of the optical fibre.

The outputs from the respective photodiodes 10 and 12 are applied to the mixing circuit 14 such that the output represents the ratio of reflected light from the optical sensor 6 at a given wavelength relative to the intensity of light applied to the sensor at that

wavelength. As the tunable filter 4 scans over the wavelength bandwidth of the light source 2 the output from the mixer 14 represents the reflection spectrum of the sensor 6 which has been normalised relative to the light applied to it and this spectrum is detected by the processor 16 which preferably comprises a spectrum analyser. It is preferable, though not essential, to normalise the reflection spectrum as described since the source 2 is unlikely to produce a uniform light intensity output over its full spectral range.

Referring to Figure 2(a) there are shown the reflection intensity I profiles for a pair of "low" and "high" reflectivity gratings which are adjacent in wavelength versus wavelength for increasing amounts of applied tensile strain to the "low" reflectivity grating. These test data are for a sensor having an array of Bragg gratings having a 2nm spectral spacing and a typical grating bandwidth of ≈ 0.4nm. The "high" (95%) reflectivity grating was kept strain free whilst the "low" (50%) reflectivity grating was strained in steps of 80$\mu\varepsilon$ up to 4000$\mu\varepsilon$, which corresponds to a 4nm change in wavelength.

Starting with the uppermost profile, which shows the sensor when no tensile strain is applied, it will be seen that the "low" reflectivity grating reflects light at a lower characteristic wavelength and the reflection peak is denoted "x" in the Figure. As tensile strain is applied to the "low" reflectivity grating, this causes an increase in the grating spacing, which causes the characteristic wavelength of the reflectivity peak x to increase and the peak moves toward and through the peak of the "high" reflectivity grating. For clarity, it should be noted that in this example no strain is applied to the "high" reflectivity grating and hence the characteristic wavelength of its reflectivity peak

remains constant.

Figure 2(b) is a plot of the wavelength shift $\Delta\lambda$ of the reflectivity peak x versus applied tensile strain. As will be seen from this Figure, the change in wavelength $\Delta\lambda$ is a linear function of applied strain and includes a band over which strain cannot be measured; this is denoted by arrows "AA" in the Figure. In this band the reflection peaks from the "low" and "high" reflectivity gratings cannot be discriminated because they spectrally overlap, as illustrated in the middle profile of Figure 2(a). In spite of this band, whose width is approximately 500 $\mu\varepsilon$, it is still possible to double the number of gratings within a given spectral range.

In the known systems the number of gratings (n) that can be incorporated into a single fibre is determined by $n \approx \Delta\lambda_{SR}/\Delta\lambda_{BG}$ where $\Delta\lambda_{SR}$ is the spectral range of the light source and $\Delta\lambda_{BG}$ is the spectral bandwidth of each fibre Bragg grating. The spectral bandwidth $\Delta\lambda_{BG}$ is necessary to ensure that reflection peaks for adjacent gratings do not cross each other. In contrast to the known sensors, the sensor of the present invention additionally encodes the reflectivity of adjacent gratings which enables discrimination of the light reflected from the respective gratings. As a result in the spectral spacing necessary between adjacent gratings is approximately halved, though the strain sensing spectral bandwidth for each grating is still $\Delta\lambda_{BG}$. The total number of gratings that can be incorporated within the fibre for a given spectral range is thus doubled.

As described above, there is a band AA in which the two gratings spectrally overlap and this band can be minimised by using narrow spectral response gratings. However, narrow

spectral response gratings will reflect less light, which will degrade the signal to noise ratio in the system. To minimise the effect of the overlapping region without the need to use ultra-narrow spectral response gratings, it is proposed in a further sensor according to the invention to replace the "low" reflectivity grating with one which is still of "low" reflectivity but reflects at two characteristic wavelengths. The spacing of the two characteristic wavelengths is selected to be at least as large as the bandwidth of the high reflectivity grating.

Referring to Figure 3, this shows for such a sensor (a) a series of plots of measured reflectivity I versus wavelength for different applied strains to the "low" reflectivity grating and (b) a plot of the measured wavelength shift $\Delta\lambda$ for the reflection peaks x,y of the low reflectivity grating versus applied strain. Referring to Figure 3(a) it will be seen that as the "low" reflectivity grating is subjected to strain the pair of reflectivity peaks (x,y) both shift at the same rate such that even when the spectral responses of the two gratings overlap at least one of the pair of peaks is always resolvable. Figure 3(b) shows the wavelength shift for both peaks (x,y) for the dual peak response as crosses and circles, respectively, versus applied strain. It will be seen that when information concerning both peaks of the dual peak response is considered the band AA over which strain cannot be measured is substantially reduced. The remaining small band is due to the relatively broad bandwidth of the high reflectivity grating. Further tests have shown that the gap is virtually eliminated if the spacing of the dual peaks is increased or if the bandwidth of the high reflectivity peak can be reduced.

It will be appreciated that the present invention is not restricted to the specific

embodiment described and that variations can be made which are within the scope of the invention. For example, in the apparatus described the intensity of the light reflected from the sensor is measured. In other embodiments it is envisaged to measure the light transmitted by the optical fibre, since the absorption loss in the fibre is negligible. Consequently, the sum of transmitted light and reflected light is substantially unity and the change in characteristic wavelength of the Bragg gratings can be determined by measuring the change in wavelength at which the fibre attenuates transmitted light. It will be further appreciated that the invention is not limited to Bragg gratings, and other forms of reflecting structures can be used provided their characteristic wavelength is affected by a change in the physical length of the structure. Although the sensor is conveniently formed as an optical fibre other forms of optical waveguide could be used though they are likely to be less convenient.

The operation of the strain sensor has been described by way of example to strain sensing within an object. It will be appreciated that the said strain sensor and apparatus can also be used to measure temperature, since a change in temperature of the grating will cause an expansion or contraction of the grating and so change the grating pitch. In such an application the optical fibre is placed in thermal contact, with the object rather than being secured to it.

CLAIMS

1. A strain sensor comprising: an optical waveguide (6) having a plurality of reflecting structures along its length, wherein each structure reflects light at a different characteristic wavelength (λ_1 to λ_{n+1}) which changes in dependence on a change of physical length of at least part of the reflecting structure; characterised in that the reflectivity of reflecting structures which reflect at characteristic wavelengths which are adjacent to each other (λ_1 and λ_2, λ_n and λ_{n+1}) are configured to be different such that the intensity of light reflected from adjacent structures can be used to discriminate between them.

2. A strain sensor according to Claim 1 in which the reflecting structures which reflect at adjacent wavelengths are configured such that one structure reflects light at one characteristic wavelength and the structure adjacent in wavelength is selected to reflect light at two characteristic wavelengths.

3. A strain sensor according to Claim 2 in which the reflecting structure which reflects light at two wavelengths is configured such that the two characteristic wavelengths are separated by at least the width of the reflection characteristic of the structure which reflects at the adjacent wavelength.

4. A strain sensor according to any preceding claim in which the optical waveguide (6) comprises an optical fibre.

5. A strain sensor according to any preceding claim in which the or each reflecting structure comprises a grating structure and wherein the change in characteristic wavelength is in consequence of a change in the pitch of the grating.

6. A strain sensor according to Claim 5 in which the or each grating structure comprises a Bragg grating.

7. A strain sensor according to Claim 5 or 6 when dependent on Claim 4 in which the optical fibre (6) includes a photo refractive dopant and the or each grating structure is optically written into the fibre.

8. A strain sensor according to Claim 7 in which the optical fibre comprises silica doped with germanium oxide.

9. Apparatus for measuring strain; comprising a sensor according to any preceding claim, a light source (2, 4) operable to apply light to the waveguide of the sensor, said light having a wavelength range which covers at least the range of wavelengths over which the reflecting structures reflect and detector means (10-16) for determining the change of characteristic wavelength at which the reflecting structures reflect light, said changes being indicative of a change in length of at least a part of the respective reflecting structure.

10. Apparatus for measuring strain according to Claim 9 in which the detector means determines the change in characteristic wavelength by measuring the

wavelengths at which the sensor reflects light.

11. Apparatus for measuring strain according to Claim 9 in which the detector means measures light transmitted by the sensor and determines the change in characteristic wavelength by measuring the changes in wavelength at which light transmission is attenuated.

12. Apparatus according to any one of Claims 9 to 11 in which the detector means further comprises means for utilising the relative magnitude of the intensity of reflected light or the relative magnitude of the intensity at which light transmission is attenuated to discriminate between reflecting structures which are adjacent in wavelength.

13. A method of measuring strain comprising; providing a sensor according to any one of Claims 1 to 8, applying light to the waveguide of the sensor, said light having a wavelength range which covers at least the range of wavelengths over which the reflecting structure reflects light, and detecting any change in the characteristic wavelength at which the reflecting structures reflect light.

14. A method according to Claim 13 comprising detecting the change in characteristic wavelength by measuring the wavelengths at which the sensor reflects light.

15. A method according to Claim 13 comprising detecting the change in

characteristic wavelength by measuring the wavelengths at which the transmission of light through the sensor is attenuated.

16. A method according to Claim 14 or Claim 15 and further comprising detecting the relative magnitude of the intensity of reflected light or the relative magnitude of the intensity at which transmitted light is attenuated to discriminate between reflecting structures which are adjacent in wavelength.

17. A method according to any one of Claims 13 to 16 and further comprising sweeping the wavelength of the light applied to the sensor.

18. A method according to any one of Claims 13 to 17 in which, when it is desired to measure strain within an object, further comprises securing a part of the waveguide having at least a part of one of the reflecting structures to the object such that a change in the physical length of at least a part of the object causes a change in the physical length of at least a part of the reflecting structure.

19. A method according to any one of Claims 13 to 17 in which, when it is desired to measure the temperature of an object, further comprises placing a part of the waveguide having at least a part of one of the reflecting structures in thermal contact with the object such that a change in the temperature of the object causes a change in the physical length of at least a part of the reflecting structure.

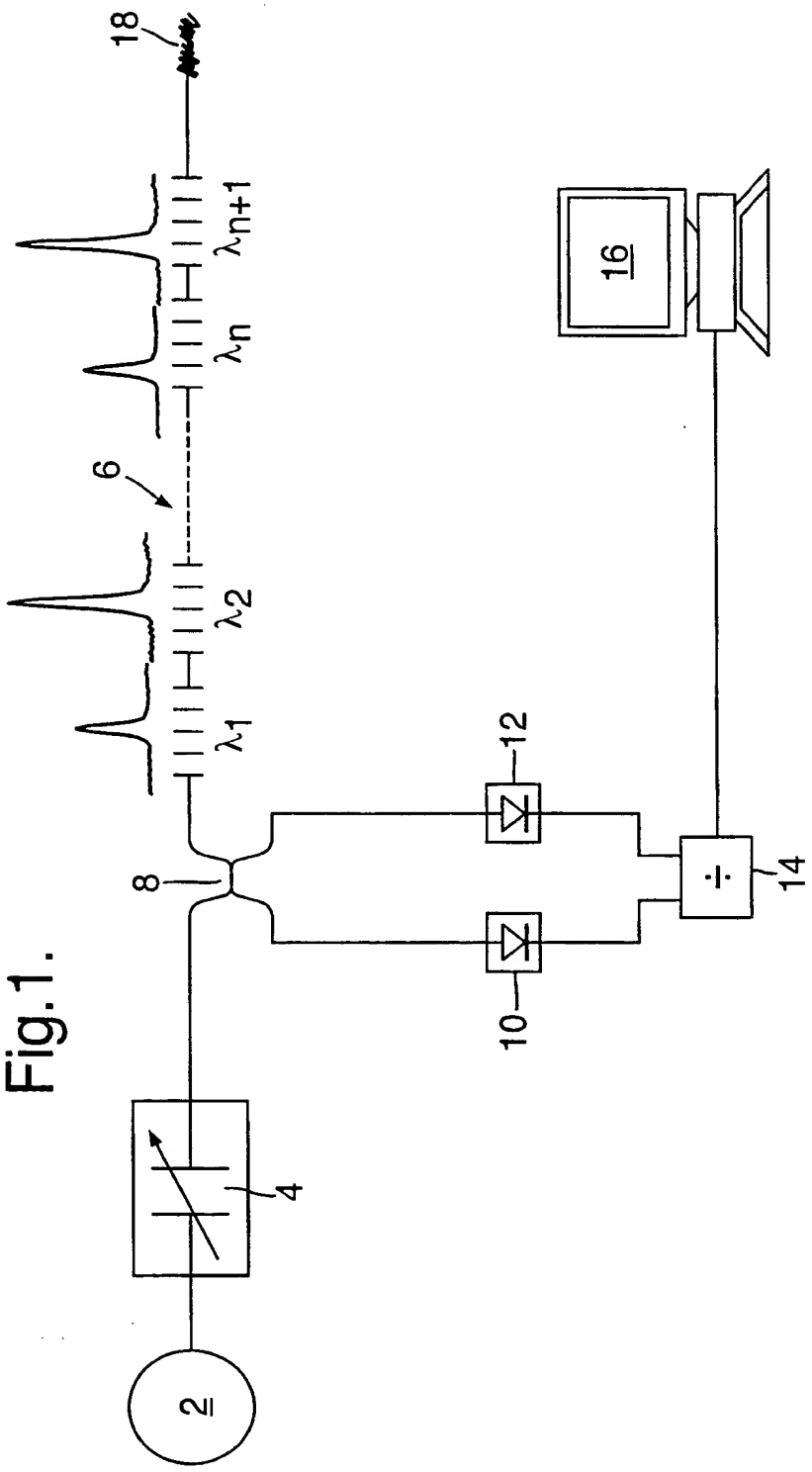


Fig.1.

Fig.2(a).

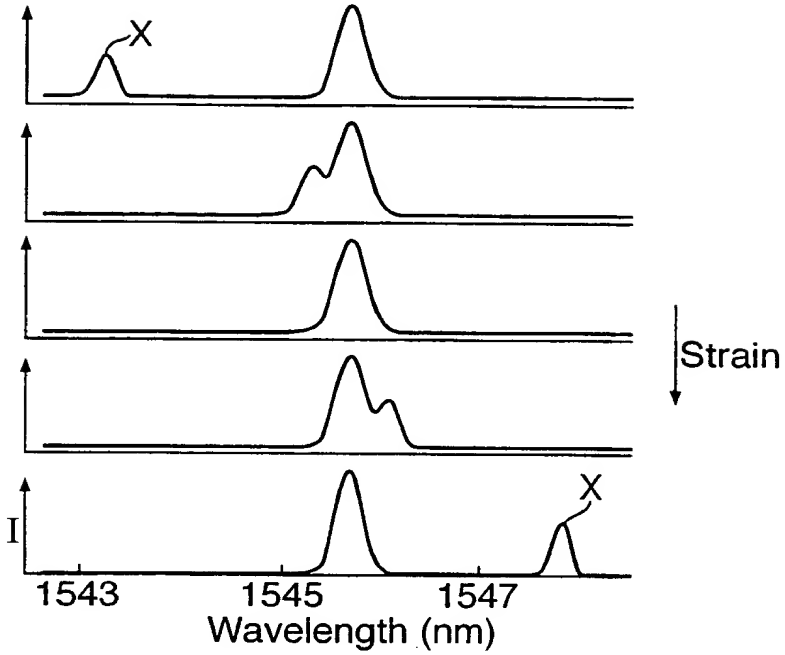

X
Strain
I
X
1543
1545
1547
Wavelength (nm)

Fig.2(b).

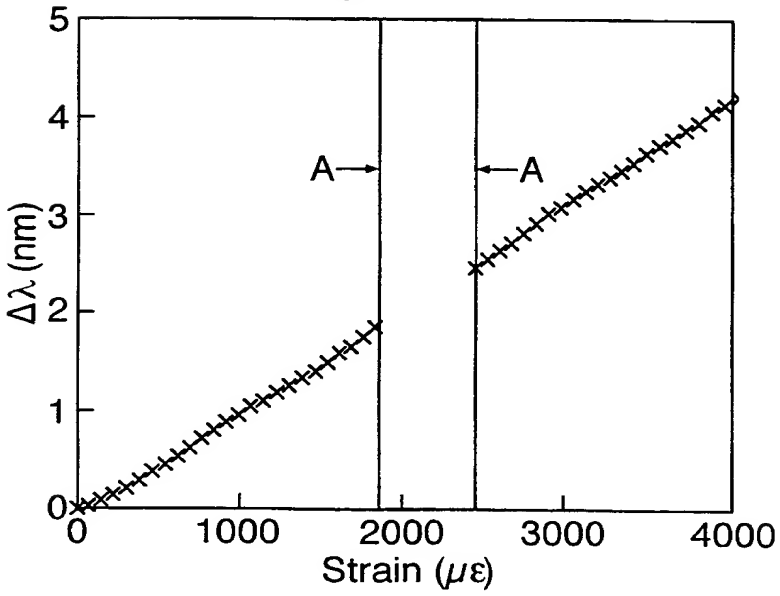

5
4
3
2
1
0
Δλ (nm)
A
A
0
1000
2000
3000
4000
Strain (με)

Fig.3(a).

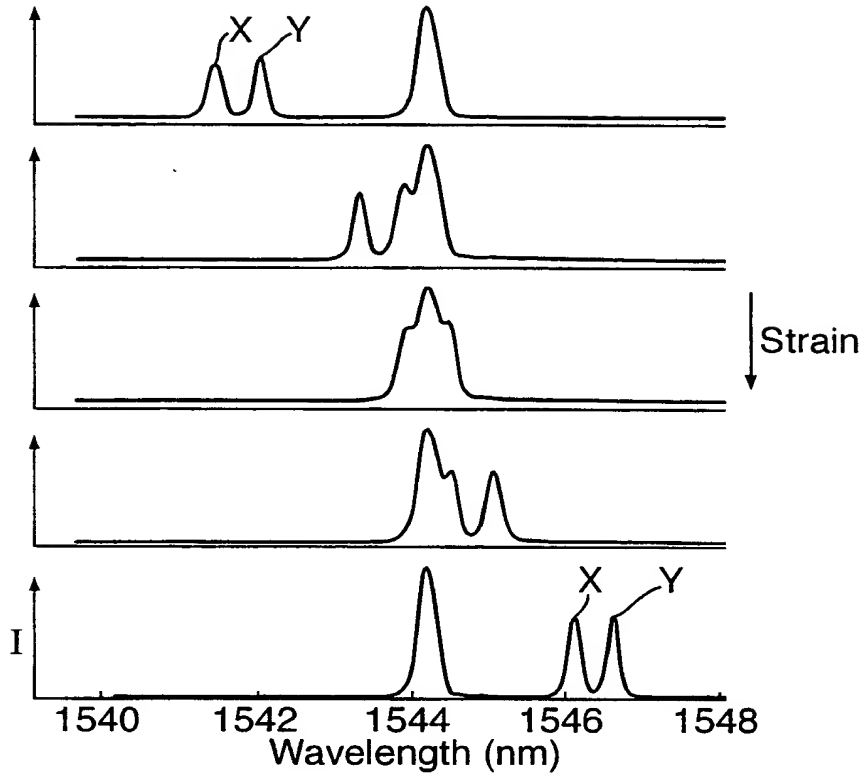
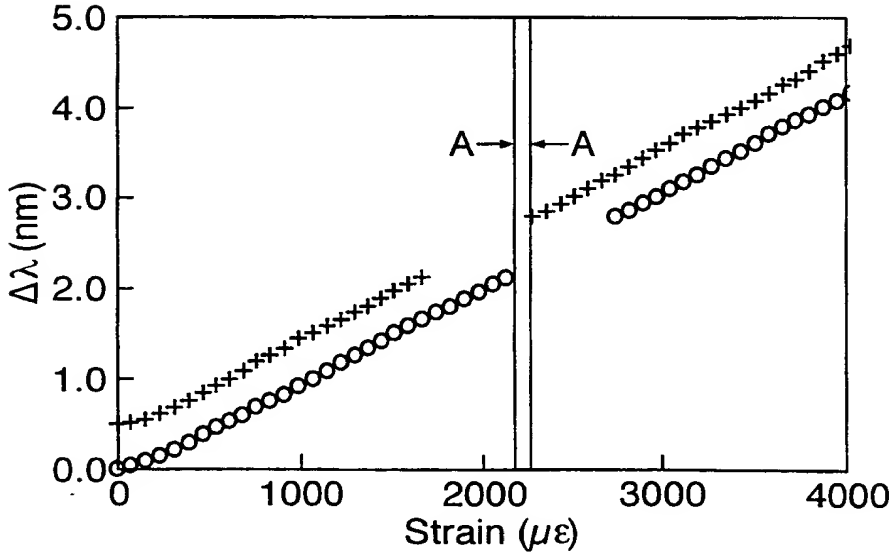

X
Y
Strain
I
X
Y
1540
1542
1544
1546
1548
Wavelength (nm)

Fig.3(b).


5.0
4.0
3.0
2.0
1.0
0.0
Δλ (nm)
A
A
0
1000
2000
3000
4000
Strain (με)

INTERNATIONAL SEARCH REPORT

Interna al Application No
PCT/GB 00/00994

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01L1/24 G01D5/353

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01L G01D G01H G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 680 489 A (KERSEY ALAN D) 21 October 1997 (1997-10-21) abstract; figures 1,4 column 1, line 5 -column 3, line 19	1-19
A	PUTNAM M A ET AL: "BROADBAND SQUARE-PULSE OPERATION OF A PASIVELY MODE-LOCKED FIBER LASTER FOR FIBER BRAGG GRATING INTERROGATION" OPTICS LETTERS,US,OPTICAL SOCIETY OF AMERICA, WASHINGTON, vol. 23, no. 2, 15 January 1998 (1998-01-15), pages 138-140, XP000733981 ISSN: 0146-9592 the whole document	1-19

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 June 2000	16/06/2000

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

Interr [redacted]al Application No
PCT/GB 00/00994

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 216 565 A (PLESSEY OVERSEAS) 1 April 1987 (1987-04-01) abstract; figures 1-3 column 3, line 25 -column 4, line 64	1-19

2

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